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Standard Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-of-Elongation Apparatus[1]

This standard is issued under the fixed designation D 828; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining tensile properties of paper and paperboard.

1.2 The procedures given in this test method are for use with constant-rate-of-elongation tensile testing equipment and as such, may be used with instruments designed for either vertical or horizontal operation, and whether manually operated or computer controlled.

1.3 These procedures are applicable for all types of paper, paperboard, paper products, and related materials within the measurement limitations of the equipment used. They are not for use with combined corrugated board.

1.4 Properties that may be determined using this test method include tensile strength, stretch, tensile energy absorption, tensile stiffness, breaking length, and tensile index.

1.5 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, or Related Product[2]

D 685 Practice for Conditioning Paper and Paper Products for Testing[2]

D 987 Method of Test for Stretch of Paper and Paper Products Under Tension[3]

D 1968 Terminology Relating to Paper and Paper Products[2]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology D 1986 or the *Dictionary of Paper.*[5]

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *breaking length, n*—the calculated limiting length of a strip of uniform width beyond which, if such strip were suspended by one end, it would break of its own weight.

3.2.2 *elastic limit, n*—the value of the tensile strength above which the ratio of the rate of change in the tensile strength to the rate of change in the elongation is no longer a constant.

3.2.3 *elastic region, n*—the region of tensile strength-elongation behavior of a specific material where the ratio of the rate of change in the tensile strength to the rate of change in the elongation is a constant.

3.2.3.1 *Discussion*—This region is frequently referred to as the linear portion of the stress-strain curve.

3.2.4 *elongation, n*—a term used as a synonym for stretch in this test method.

3.2.5 *line contact grips, n*—grips or jaws on a tensile testing machine having a clamping zone for gripping the specimen comprised of a cylindrical and a flat surface or two cylindrical surfaces whose axes are parallel.

3.2.6 *percentage elongation, n*—a mathematical quantity used to express elongation (stretch) as a percentage increase in the length of a test specimen at rupture, in comparison to its length at the beginning of a tensile test carried to rupture under the conditions specified in this test method.

3.2.7 *stretch, n*—the maximum tensile strain developed in a test specimen prior to rupture in a tensile test that has been carried to rupture under the conditions specified in this test method.

3.2.8 *tensile energy absorption, n*—a mathematical quantity used to express the energy per area of the original specimen absorbed by the specimen prior to rupture in a tensile test carried to rupture under the conditions specified in this test method.

3.2.9 *tensile index, n*—a mathematical quantity calculated by dividing the tensile strength of a sample by its grammage.

3.2.10 *tensile stiffness, n*—a mathematical quantity calculated by dividing the slope of the elastic region by the specimen width.

3.2.11 *tensile stiffness, n*—a mathematical quantity expressing the ratio of tensile strength to tensile strain in the elastic region of the tensile strength-elongation behavior of a specific material.

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[1] This test method is under the jurisdiction of ASTM Committee D-6 on Paper and Paper Products and is the direct responsibility of Subcommittee D06.92 on Test Methods.

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[2] *Annual Book of ASTM Standards*, Vol 15.09.

[3] Discontinued, see *1968 Annual Book of ASTM Standards*, Part 15.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Formerly published by American Paper and Pulp Assoc. (currently API), New York, NY.

3.2.12 *tensile strength, n*—the maximum tensile force developed per unit width of test specimen prior to rupture in a tensile test which has been carried to rupture under the conditions specified in this test method.

3.2.13 *tensile work, n*—a term having the same meaning as *tensile energy absorption* when used in the context of this test method.

4. Significance and Use

4.1 The tensile properties measured in this test method are fundamental properties associated with the manufacture, or end use, or both, of paper and paper products. They may be influenced by, or indicative of the type fibers used or the treatment of the fibers, or both, in a particular paper. They may also be influenced by or indicative of specific manufacturing procedures used in producing a specific paper or paper product. Likewise, paper converting operations may significantly impact properties measured using this test method, and this test method may be used to measure and understand such effects.

4.2 Tensile strength is indicative of the serviceability of many papers, such as wrapping, bag, gummed tape, and cable wrapping, that are subjected to direct tensile stress. The tensile strength of printing papers is indicative of the potential resistance to web breaking during printing and other converting operations and during travel of the web from the roll through the equipment.

4.3 Stretch, and sometimes tensile stiffness are indicative of the ability of the paper to conform to a desired contour. These are important properties of creped papers, towels, napkins, decorative papers, industrially used paper tapes (both creped and pleated), bags, and liners for cans, barrels, and cartons.

4.4 Tensile energy absorption is a measure of the ability of a paper to absorb energy at the strain rate of the test, and indicates durability of papers that are subjected to repetitive straining and stressing, such as multiwall sack papers.

4.5 Tensile stiffness often gives a better indication of the mechanical response of the sheet to converting forces than do tensile rupture criteria.

5. Apparatus

5.1 *Tensile Testing Machine*, of the constant-rate-of-elongation type conforming to the following criteria:

5.1.1 Two line contact grips or jaws for gripping the test specimens, with the line of contact perpendicular to the direction of the applied load, and with means for controlling and adjusting the clamping pressure.

NOTE 1—There are certain grades of paper that may be damaged by line contact grips. In these cases, as agreed upon between the users of this test method, other grips may be substituted, and that fact stated in the report.

5.1.1.1 The clamping surfaces of the two grips must be in the same plane and so aligned that they hold the test specimen in that plane throughout the test.

5.1.2 The distance between the line contact gripping zones of the grips at the beginning of a test must be adjustable and resettable to ±0.5 mm (±0.02 in.) for the specified initial test span (see 8.1 and 10.3.2).

5.1.3 The rate of separation of the two grips must be 25.4 ± 5.0 mm/min (1.0 ± 0.2 in./min) or as otherwise noted (see 10.3.4), and once set, must be resettable and constant at the required rate to ±4 % of the specified value.

5.1.4 The tensile testing machine must be equipped with a load measuring device and a recorder or other suitable indicator of the measured load at points of interest during the test, an example of which might be a micro processor and digital readout device or cathode ray tube screen, capable of reading the measured loading force accurately to 0.25 % of the full range of the load measuring device. The load measuring circuitry must be capable of accurate calibration, and must maintain that calibration accuracy to ±0.5 % of the full-scale value.

5.1.5 The tensile testing machine must be equipped with an elongation measuring device and a recorder or other suitable indicator of the measured elongation at points of interest, an example of which might be a microprocessor and digital readout device or cathode ray tube screen, capable of accurate calibration and of indicating the elongation values to a readability and accuracy of ±0.05 % stretch (that is ±0.09-mm elongation for an original specimen test span of 180 mm).

5.1.6 The tensile testing machine must be capable of providing the measurement data required for making the calculations specified in Section 11, whether by presentation of data in the form of a recorder trace of the tensile force-elongation behavior of the material being tested such that data required by the user can be readily determined from the recorder trace, or whether by storage of required data points in a form usable and retrieveable by the user for calculations as specified in Section 11, or whether by including calculation algorithms suitable for direct display of the calculations specified in Section 11. Where calculation algorithms are included, it is the responsibility of the manufacturer of the instrument to clearly document the calculation basis for the values that are reported, and that they do or do not comply with the calculations specified in Section 11. The user of the instrument must, in turn, determine that reported values are suitable for any particular information need. Numerous other calculations may be based on the tensile strength-elongation of a material, and may be included in an instrument used for making the measurements described in this test method, as agreed upon between the manufacturer and the purchaser of the instrument.

5.2 *Alignment Jig*, to facilitate centering and aligning the specimen in the instrument grips, so that the clamping lines of contact are perpendicular to the direction of the applied force and the center line (long dimension) of the specimen coincides with the direction of the applied force. Use optional, as agreed upon between the users of this test method. Such a device is described in TAPPI Journal (1)[6].

5.3 *Planimeter or Integrator*, to measure the area beneath the load-elongation curve or to compute directly the work to rupture. The specific characteristics of the testing machine used will dictate the need for this device. Most modern electronic tensile testing machines include the necessary

[6] The boldface numbers given in parentheses refer to a list of references at the end of the text.

calculation capabilities in the software resident in the instrument. See 5.1.6.

5.4 *Specimen Cutter*, a device capable of cutting specimens for testing that are uniform in width to within at least ±0.5 mm (±0.02 in.) or less of the specified specimen width, and with edges parallel to within 0.1 mm (0.004 in.). The double-blade strip cutter of the JDC-type is quite satisfactory for this requirement. Other cutting dies may also be used, provided they are found to comply with or exceed the tolerances stated herein. Single-blade "paper cutters" do not comply with the requirements for a specimen cutter for purposes of this test method.

5.5 *Magnifier and Scale or Similar Optical Comparator*, for use in measuring specimen widths and determining that specimens comply with 5.4. It is important to understand that the requirements of 5.4 apply to the test specimen, not to the specimen cutter. The tolerances to which the cutter or cutting die itself must be designed are those that produce *test specimens* of the stated tolerance.

NOTE 2—Automated tensile testing instruments providing automated sample handling, laboratory management, or data acquisition, or any of these in combination, are available. These instruments provide features not limited to calibration, calibration check, automation of testing sequence, storing of testing programs including rate of grip separation or distance of grip separation, or both, cutting of test strips, acquiring of test data, and accurately determining tensile breaking properties including those listed in Section 11. This test method may be used with any such equipment, provided the equipment complies with the requirements of Section 5.

6. Sampling

6.1 *Acceptance Sampling*—Acceptance sampling shall be done in accordance with Practice D 585.

6.2 *Sampling for Other Purposes*—The sampling and the number of test specimens depend on the purpose of the testing. Practice E 122 is recommended.

7. Test Specimens

7.1 The standard dimension for test specimens required for performing this test method is 25.4 ± 0.5 mm (1.00 ± 0.02 in.) wide and of such length, usually about 254 mm (10.0 in.) to allow sufficient specimen for clamping in the instrument grips when the standard distance between the grip clamping zones is 180 ± 5 mm (7.1 ± 0.2 in.).

7.1.1 A common width dimension, found in many ISO Standards and used for some specific grades of paper based on specification or agreement between the buyer and the seller, is 15.0 mm (0.591 in.). The limits of precision for the specimen width stated in 5.4 apply (±0.5 mm [±0.02 in.]), thus the narrower specimen width may introduce a slightly greater variability into tensile strength results, and values calculated from tensile strength such as breaking length.

7.1.2 Specifications requiring specimen widths other than those in 7.1 and 7.1.1 may be encountered. Specimen width used must always be included in the report when it deviates from 7.1. The impact of specimen width is addressed in Annex A1.

7.2 From each conditioned test unit of the sample, cut ten test specimens in each of the two principle directions of the paper having the dimension stated in 7.1 using a specimen cutter complying with 5.4.

7.3 Ensure that the specimen strips chosen for testing are free from abnormalities such as creases, holes, wrinkles, or other features not typical of the paper itself that may impact tensile strength values.

7.4 In some cases, particularly including converted paper products, it may be impossible to obtain specimens complying with 7.1 with regard to specimen length, or 7.3 with regard to freedom from abnormalities, or both, because of perforations, folds, embossing, printing, or other deliberately added product design features. In such cases, as agreed upon between the buyer and the seller, or required in relevent specifications, smaller initial distance between the two instrument grips may be required, with accompanying requirements for shorter test specimens. In addition, a change in rate of grip separation may be required. In such cases the deviation from this test method must be reported. Further information on these points may be found in Annex A1.

7.5 In some cases, it may be agreed upon between the buyer and the seller, or required in relevant specifications to perform testing on test specimens of lesser or greater width than that specified in 7.1. In such cases, the deviation from this test method must be reported. Further information on this point may be found in Annex A1.

8. Calibration

8.1 Because of the large number of tensile testing machines available that conform to the requirements of 5.1, specific calibration procedures for individual instruments is beyond the scope of this test method, and must be obtained from the manufacturer of the equipment. The following are general considerations that must be included, along with other considerations unique to specific instruments, as part of calibration procedures for use with this test method.

8.1.1 Regularly inspect the machine for cleanliness and for faults such as wear, misalignment, loose parts, or damage. Clean, grease, or otherwise service the machine at regular intervals, as recommended by the manufacturer or determined by the user of a particular machine. Make all necessary repairs when faults are found.

8.1.2 Level the machine accurately in the two principle directions using a carpenter's level or similar device.

8.1.3 Align the clamping grips that hold the specimen in the plane of the applied load, as required in 5.1.1.

8.1.4 Position the specimen grips as required in 5.1.2, or as agreed upon between the buyer and the seller in 7.4. Correct distance between the required line contact gripping zones may be verified by measuring the distance between the centers of the line clamp impressions produced on strips of thin metal foil.

8.1.5 Determine and adjust the clamping pressure on the specimen grips so that neither slippage or specimen damage occurs. Papers prepared from more highly hydrated or beaten fibers, such as tracing paper or glassine, present the most difficult gripping problems. For use with the widest possible range of papers, adjustment of grip pressure by making tests on strong tracing paper is generally satisfactory. Excessive pressure at the grip is evidenced by straightline breaks in, and immediately adjacent to the clamping zone. Insufficient pressure is evidenced by an abrupt discontinuity in the measured tensile strength prior to specimen rupture, or a wider than normal impression of the clamping line on the specimen after rupture, or both. Some level of experi-

mentation will be required to achieve a satisfactory clamping pressure for specific types of paper or paper products.

8.1.6 After it is established that the testing machine is in good working order and has been properly leveled, periodic calibration of the load measuring system with standard weights is required. For referee testing and to comply with many different quality management programs, or both, the weights used should have traceability to a national standardizing organization such as NIST. Weights covering the entire range of the load-measuring component in the testing machine should be available, and should include about ten weights spaced fairly evenly thoughout the measuring range. Attach the weights to the clamp connected to the load-measuring device in a suitable manner or as directed in the instrument instructions, being sure to eliminate the weight of any weight support from the indicated value of the weight itself. Note the value measured when the system is in equilibrium. As stated in 5.1.4, allowable deviation from true weight is ±0.5 % of the full-scale range of the measuring component.

8.1.7 Periodic verification of the extension measuring system is required. Set the clamping grips to a specific separation as required in 5.1.2 or agreed upon based on 7.4. Verify the exact separation of the grips to the nearest 0.05 mm using a caliper of verified accuracy. Operate the grip separating system (commonly called the cross head on vertical tensile testing machines) as specified in 5.1.3 for a desired time period, measured to the nearest 0.1 s. Based on the speed at which the cross head is set to travel (25.4 mm/min as specified in 5.1.3, or some other speed) calculate the expected distance between grips (original separation plus the distance represented by multiplying the cross-head speed times the seconds of travel). Measure the actual distance with the caliper. The measured and calculated distances must agree within ±0.09 mm (see 5.1.5). Repeat for several different time intervals within the expected 15 to 30-s duration of a tensile test to rupture (see 10.3.4).

8.2 Perform such other maintenance or calibration, or both, as may be required for the proper performance of the tensile testing machine used such that it complies with all requirements of this test method and all recommended calibration and maintenance programs of the manufacturer.

9. Conditioning

9.1 Condition the samples in accordance with Method D 685.

9.1.1 Exposure of samples to high relative humidity prior to preconditioning and conditioning may lead to erratic results with either a decrease or increase in tensile strength or stretch, or both. Careful protection of the sample from extremes in humidity from the time of sampling until testing is very important.

10. Procedure

10.1 Perform all testing in an environment as specified in Method D 685.

10.2 Adjust and calibrate the testing machine as required in Section 8.

10.3 The standard testing parameters required by this test method are as follows:

10.3.1 *Specimen Width*—25.4 mm (1.00 in.), see 7.1,

10.3.2 *Effective Specimen Length (Grip Separation at Start of Test)*—180 mm (7.1 in.), see 7.1,

10.3.3 *Nominal Specimen Length*—254 mm, see 7.1, and

10.3.4 *Rate of Grip Separation During Test*—25.4 mm/min, see 5.1.3.

10.3.4.1 This rate of grip separation generally results in sample rupture in less than 30 s and more than 10 s. In cases where rupture consistently requires greater than 30 s, a more rapid rate of grip separation must be used, so that sample rupture occurs in between 10 and 30 s. Where a grip separation other than that stated in 10.3.4 is used, the actual grip separation speed must be reported, as required in 12.1.5.

10.3.5 For purposes of testing shipping sack and shipping sack paper for compliance with tensile energy absorption carrier and federal requirements,[7] an effective specimen length (grip separation at start of test) of 122 mm (4.2 in.) and a rate of grip separation of 25.4 mm/min must be used.

10.3.6 Adjust data recording components for data recording as required for the material being tested, particularly with regard to the full-scale range of the load measuring system.

10.3.7 Where specimen tensile strength is unknown, preliminary tests may be required to achieve proper instrument settings.

10.3.8 Place one end of a test specimen into one of the instrument grips, align it, and clamp it in place. Place the other end of the test specimen in the other grip. Carefully remove slack, but to not stretch the specimen. Close the second clamp. While handling the test specimen, avoid touching the area that will be between the two clamping zones with the fingers.

10.3.9 Verify correct clamping pressure (see 8.1.5).

10.3.10 Test ten specimens in each principle direction for each test unit.

10.3.11 Reject any test value in which the test specimen slips in the jaws, breaks within the clamping zone, or shows evidence of uneven stretching across its width. Also, reject any test values for test specimens that break within 5 mm (0.2 in.) of the clamping zone if further inspection indicates the break location is due to improper clamping conditions or misalignment of the specimen. If more than 20 % of the specimens for a given sample are rejected, reject all readings for the sample, inspect the testing machine for conformance with specifications, and take any steps necessary to correct problems identified.

10.3.12 Record values for tensile strength, elongation, and other calculated quantities as required or provided for by the instrument being used for each specimen strip tested. Values may be automatically accumulated in a data file in instrument software if the instrument is so equipped, or transferred directly into a central data system.

10.3.13 For any case in which deviations from this procedure are made, particularly because of small sample length, all deviations and the reason for them must be documented in the report.

[7] Freight Classification Rule 40, National Motor Freight Classification, Item 200, UUS 48, and Department of Transportation 178.236.

11. Calculation and Interpretation of Results

11.1 For each test unit and in each principle direction, calculate the average value for the tensile strength at rupture using the data from 10.3.12. Add the value for each individual specimen and divide by the total number of specimens tested.

11.1.1 The customary units of tensile strength are force per width. In cases where a 1.00-in. specimen is tested, the customary unit is force per inch. In cases where a 15-mm specimen is tested, customary units are force per 15-mm. Where other specimen widths are required, the specification will generally state units to be used in reporting data.

11.2 In like manner to that described for tensile strength in 11.1, calculate the average value for elongation at rupture. This value may be reported as the percentage of the original effective specimen length (see 10.3.2), if desired.

11.3 Using instrument software, a planimeter value from a recorder trace of the test data, or other convenient means, calculate the average tensile energy absorption prior to rupture for each principle direction of each test unit, again by adding together the individual test values of tensile energy absorption and dividing by the total specimens tested.

11.3.1 The following formulas may be used to calculate tensile energy absorption in joules per square meter. See Annex A1 for derivation of constants:

$$TEA = 1 \times 10^6\, A/LW$$
$$= 9.807 \times 10^4\, A'/LW$$
$$= 175.1\, a/lw$$

where:

TEA = tensile energy absorption, J/m^2,
L = initial test span, mm,
W = specimen width, mm,
A = area under the load-elongation curve, J, and
A' = area under the load-elongation curve, kgf·cm.

11.3.2 While the units in 11.3.1 are preferred, if foot pound-force per square foot are desired, use the following formula:

$$tea = 12\, a/lw$$

where:

tea = tensile energy absorption, ft·lbf/ft^2,
a = area under the load-elongation curve, lbf·in.,
l = initial test span, in., and
w = specimen width, in.

11.3.3 To convert from tea to TEA, use the following formula:

$$TEA = 14.60 \times tea$$

11.4 Using instrument software or a recorder trace of the test data, calculate tensile stiffness, if desired, as the average slope of the elastic region of the test data in agreed units of force per elongation (strain). For purposes of this analysis, the elastic region over which this average value is determined must begin at a load value no lower than 5 % of the elastic limit, and must not go beyond 75 % of the elastic limit, and the data used must comprise at least 20 % of the elastic region of the test data.

11.5 For purposes of determining specimen rupture in 11.1, 11.2, and 11.3, the specimen will be deemed to have ruptured when maximum tensile load has been reached and the tensile load has dropped no more than 0.25 % of the instrument full-scale load below the maximum load. This procedure is applicable so long as maximum strain occurs at rupture, which is usually the case for paper samples. For instruments including software packages to determine rupture, it is the responsibility of the user to determine that the conditions stated here are fulfilled. Frequently, instrument "peak" (rupture) detecting algorithms are variable by user input, to allow the instruments to be used for a wide variety of testing activities.

11.6 Calculate breaking length, when required, using the following formula:

$$BL = 102\,000\,(T/R)$$
$$= 3\,658\,(T'/R')$$

where:

BL = breaking length, m,
T = tensile strength, kN/m,
R = grammage, g/m^2,
T' = tensile strength, lbf/in., and
R' = mass per unit area, lb/1000 ft^2.

11.6.1 It is customary to measure R or R' under "air dry" conditions, rather than under the conditions specified in Method D 685. The buyer and seller must agree on the exact calculation convention being used when breaking length is included in a specification.

11.7 Calculate tensile index, when required, using the following formula:

$$TI = 1000\,(T/R)$$
$$= 36.87\,(T'/R')$$

where:

TI = tensile index, N·m/g,
T, T', R, and R' are in accordance with 11.6.

11.8 All of the above calculations are available in software packages for use within test instruments themselves, or within personal computer or larger laboratory computerized data management systems. It is the responsibility of the user to determine exactly what calculations and units are required, and that desired data is being generated.

11.9 The following are the required units for tensile properties determined using this test method in the absence of agreements between the buyer and the seller to use other units:

11.9.1 Tensile strength, kN/m,
11.9.2 Elongation, %,
11.9.3 Tensile energy absorption, J/m^2,
11.9.4 Tensile stiffness, kN/m,
11.9.5 Breaking length, m, and
11.9.6 Tensile index, N·m/g.

12. Report

12.1 Report at least the following information for each test unit in each principle direction to three significant figures. Units of reporting are to be as specified in 11.9 unless the seller and the buyer agree to use other units:

12.1.1 Average tensile strength and range or standard deviation,

12.1.2 Average percentage elongation and range or standard deviation,

12.1.3 Average tensile energy absorption and range or standard deviation,

12.1.4 The number of tests rejected and the reason for rejection, and

12.1.5 Any deviations from the procedures specified as standard in this test method, including, but not limited to, deviations in sample length or width, rate of jaw separation, clamping and configurations, or features of equipment design.

13. Precision and Bias

13.1 *Repeatability*—The critical limits of repeatability between which two test results, each representing the average of values determined on ten test specimens of the same test unit within the same laboratory by the same operator will fall 95 % of the time, calculated as the percentage of the average of the two results are as follows:

13.1.1 *Tensile Strength*—5 %,

13.1.2 *Stretch*—9 %, and

13.1.3 *Tensile Energy Absorption*—10 to 16 %.

13.2 *Reproducibility*—The critical limits of reproducibility between which two test results, each representing the average of values determined on ten test specimens of the same test unit within different laboratories by different operators will fall 95 % of the time, calculated as the percentage of the average of the two results are as follows:

13.2.1 *Tensile Strength*—10 %,

13.2.2 *Stretch*—25 %, and

13.2.3 *Tensile Energy Absorption*—22 to 36 %.

13.3 These estimates of precision were reported in TAPPI Journal (3).

13.4 Additional data for estimating precision are available through the Collaborative Testing Program.[8]

13.5 *Bias*—No statement is made regarding the bias of the quantities measured in this test method for tensile breaking strength of paper and board, and related calculated quantities, because all properties measured are dependent upon the specific test conditions specified in this test method.

14. Keywords

14.1 breaking length; elongation; paper; paper products; percentage elongation; tensile energy absorption; tensile index; tensile strength

[8] Managed by Collaborative Testing Services, Herndon, VA.

ANNEX

(Mandatory Information)

A1. TENSILE TESTING EQUIPMENT COVERED BY THIS TEST METHOD

A1.1 The previous version of this test method measured only the tensile breaking properties of paper, but permitted a wider variety of options with regard to testing instrumentation, including pendulum, inclined plane, and spring-driven units. Most of these instruments do not comply with one or more of the requirements of 5.1. In addition, the data produced by these instruments may be insufficient for making one or more of the calculations specified in Section 11. Method of Test D 987, for use in measuring stretch of paper and paper products, referenced in the previous version of this test method, was discontinued in 1968 and is no longer considered reliable for making stretch measurements to the precision and bias required in this test method. It was the decision of the subcommittee responsible for this test method to produce a test method for measuring a wide range of tensile properties of paper and paper products using widely available, current measurement equipment. It should be obvious that equipment types not complying with this test method can still be used for testing purposes, but results produced cannot be stated to comply with this test method.

A1.2 Paper as a physical material is both visco-elastic and hygroscopic. The consequence of this fact is that any change in the temperature or humidity, or both, at which samples or test specimens are conditioned or tested, and any change in the rate at which stress is applied to a specimen (in the context of this test method, the rate of strain or, more specifically, rate of grip separation), may cause changes in measured results. Only when the conditions stated in this test method are adhered to with rigor can precise results in good agreement be achieved within, between, or among persons, laboratories, or companies, including various buyers and sellers, who may use this test method. It is recognized, however, that certain papers or paper products may be impossible to test under the standard conditions of this test method. Some of the more commonly encountered variations in procedure and their effect on test results are as follows:

A1.2.1 *Test Specimen Length:*

A1.2.1.1 If test specimens of reduced length must be used for reasons in 7.3, 7.4, or other reasons, as agreed upon between the buyer and the seller, recommended effective specimen lengths (distance between the specimen gripping zones) are 100 ± 5 mm (4 ± 0.2 in.) or 50 ± 2 mm (2 ± 0.1 in.).

A1.2.1.2 Shorter specimen lengths generally result in higher values for tensile strength, elongation, and tensile energy absorption at rupture (the three quantities are mathematically and structurally related) than the standard length of 180 mm, and reduced precision for elongation measurements.

A1.2.1.3 Longer specimen lengths generally result in lower values for tensile strength, elongation, and tensile energy absorption at rupture.

A1.2.1.4 The decrease in tensile related properties at rupture that occurs as a function of increased specimen length has two primary sources: (*1*) test specimens rupture at the weakest point along their length; and (*2*) as the specimen length increases, the probability of including an even weaker portion of material in the specimen increases.

A1.2.1.5 A consequence of A1.2.1.4 is that the impact of specimen length changes will be greater for papers with poor formation, because their internal structural variability is

TABLE A1.1 Predicted Changes in Tensile Strength at Rupture[A]

Coefficient of Variation for 200-mm Specimen, %	Predicted Change in Rupture Tensile Strength, % Specimen Length, mm				
	50	100	200	300	400
2	2.7	1.2	...	−0.7	−1.1
4	5.4	2.5	...	−1.3	−2.2
6	8.0	3.7	...	−2.0	−3.3
8	10.7	5.0	...	−2.6	−4.3
10	13.4	6.2	...	−3.3	−5.4

[A] As related to specimen variability and tensile strength at a specimen length of 200 mm when specimen length is varied from 50 to 400 mm.

greater and the probability of incorporation of even weaker portions of material with a lesser increase in length becomes greater.

A1.2.1.6 Calculations based on the work of Pierce (3) and others have been used to develop a predictive model of tensile strength at rupture as a function of both coefficient of variation and rupture load of the paper for a specimen length of 200 mm as the specimen length varies. Table A1.1 shows the results of this work (3, 4).

A1.2.1.7 It should be clear that any change in specimen length will result in changes in the values of the properties measured in this test method. Even when circumstances require such change, it must be clearly documented and agreed in advance, and reported as part of the test method report, as required in 12.1.5.

A1.2.2 *Effect of Test Specimen Width*—There is little impact from varying the test specimen width in the range from 12 to 50 mm (approximately 0.5 to 2.0 in.) except in the case of unbeaten long fibers where the difference may be appreciable. However, any deviation from the required width of 25.4 mm (1.00 in.) must be clearly reported, as required in 12.1.5.

A1.2.3 *Effect of Grip Separation Speed:*

A1.2.3.1 Increasing the rate of grip separation by a factor of two for a constant specimen length will generally increase tensile strength at rupture values and may increase tensile energy absorption. In some cases, an accompanying decrease in elongation may result in tensile energy absorption values that are nearly independent of grip separation speed.

A1.2.3.2 If shorter test specimen lengths are required (see 7.4), the rate of grip separation should be reduced in proportion to the reduction in specimen length. For example, if the specimen length is reduced from 180 to 90 mm (a reduction of a factor of 2) the grip separation rate should be reduced by the same factor of 2 for 25.4 to 12.7 mm/min. In this way, the rate of sample elongation (mm/min/mm) remains identical to that required for the standard specimen length. In any case where grip separation differs from that specified in 10.3.4, this deviation must be reported as required in 12.1.5.

A1.2.3.3 Previous versions of this test method permitted variation in the rate of sample elongation, partly so as to accommodate a variety of testing machines some of which were incapable of operating at a constant rate of elongation. The "time to rupture" was kept constant within certain limits, but data variation as described in A1.2.3.1 occurred. However, the requirement in 10.3.4.1 that specimens rupture within 30 s or less will be fulfilled only for papers whose elongation is 12.7 mm (the distance the grips will elongate the specimen in 30 s traveling at 25.4 mm/min) or less. For the specimen of standard, this means that if the percent elongating consistently exceeds about 7 %, a faster rate of grip separation will be required. Many creped papers, including some tissue products, have values for percent elongation exceeding 7 %, and will require grip separation speeds in excess of 25.4 mm/min. The actual grip separation used must be reported, as required in 12.1.5.

A1.2.4 The derivation of the constants found in 11.3.1 is as follows:

$$TEA\ (J/m^2) = \frac{A\ (J)}{L\ (mm)} \left| \frac{}{W\ (mm)} \right| \frac{(1000\ mm)^2}{m^2}$$

$$= 1 \times 10^6\ A/LW$$

$$TEA\ (J/m^2) = \frac{A\ (kg_f)\ (cm)}{L\ (mm)} \left| \frac{}{W\ (mm)} \right| \frac{(1000\ mm)^2}{m^2} \left| \frac{m}{100\ cm} \right.$$

$$\times \frac{IJ}{Nm} \left| \frac{N \cdot S^2}{(kg_m)\ (m)} \right| \frac{9.807\ (kg_m)\ (m)}{(kg_f)S^2}$$

$$= 9.807 \times 10^4\ A'/LW$$

$$TEA\ (J/m^2) = \frac{a\ (lb_f\ in.)}{I\ (in.)} \left| \frac{J}{w\ (in.)\ 0.7376\ ft \cdot lb} \right.$$

$$\times \frac{ft}{12\ in.} \left| \frac{(39.37\ in.)^2}{m^2} \right.$$

$$= 175.1\ a/lw$$

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(4) Wink, W. A., Hardacker, K. W., Van Eperen, R. H., and Van den Akker, J. A., "The Effect of Initial Span on the Measured Tensile Properties of Paper," *Tappi 47* (1): 47, 1964.

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DETERMINATION OF ORGANIC CONTENT OF GLASS FIBER FILTERS

1. Label an appropriate number of crucibles (50 ml capacity) and covers.

2. Heat crucibles and covers in a muffle furnace for 1 hour at 400°C.

3. Place the cover on the crucible, remove from the oven, and cool.

4. After the crucible has cooled sufficiently, place in a desiccator overnight (16 hours). The cover should be adjar to allow any moisture in the crucible to escape.

5. Replace the cover on the crucible, and weigh crucible, and cover to the nearest 0.001 mg, and record in a notebook.

6. Repeat steps 2 through 5 four more times or until successive weighings agree to within 0.2 mg.

7. Average the last 2 crucible weights, and record as We.

8. Cut a 4" x 4" (103.23 CM^2) square from each filter to be tested.

9. Fold, put in a conditioned crucible, and place crucible, cover, and filter in a desiccator overnight (16 hours). Cover is adjar to allow moisture to escape from the filter.

10. Weigh crucible, cover, and contents on three successive days or until successive weighings agree to within 0.2 mg. Replace crucible with filter in the desiccator between weighings.

11. Average the last 2 weighings, and record as Wi.

12. Place crucible containing the filter in a muffle furnace for 1 hour at 400°C. Cover should be adjar to allow moisture to escape while crucible is in the oven.

13. Put cover on the crucible, cool, and place in a desiccator overnight (16 hours). Cover should be adjar to allow moisture to escape while crucible is in the desiccator.

14. Replace the cover, and weigh crucible, cover, and filter residue, and record weight in a notebook.

15. Repeat steps 12 through 14 four more times or until successive weighings agree to within 0.2 mg.

16. Average last two weighings, and record as Wf.

17. Calculate the percent weight loss as follows:

$$\% \text{ Wt. loss} = \frac{Wi - Wf}{Wi - We} \times 100$$

Attachment B-5A

EMSL/EPA/RTP Hi-Vol Filter Flow Rate Acceptance Test for Quartz Filters for the SSI Samplers

Equipment Needed:
- SSI Sampler
- Mercury Manometer
- Roots Meter
- Barometer
- Variable Voltage Transformer
- Thermometer
- EPA Standard 7-Hole Resistance Plate

1. Adjust mercury manometer scale to zero and open manometer outlet.
2. With a standard EPA 7-hole resistance plate in filter holder, turn on motor and allow one minute warm-up.
3. Adjust the variable voltage transformer until the flow rate through the roots meter is 40 cu ft/min (1.13 M^3/min). (1 cu ft/min = .028 M^3/min.) (Follow steps 5 through 11 to determine flow rate).
4. Turn off motor and remove the 7-hole resistance plate.
5. Place filter to be tested in sample holder, turn on motor, and allow one minute warm-up.
6. Start timing the flow through the roots meter for time period t. (In order that a sufficent volume of air pass through the roots meter, t should be 2 minutes.)
7. Record volume (V_I) indicated on roots meter at beginning of time period t.
8. Record volume (V_F) indicated on roots meter at end of time period t.
9. Record atmospheric pressure (P) in mm of Hg, temperature (T) in °C, and pressure difference (ΔP) indicated on mercury manometer.
10. Turn off motor and remove filter.
11. Calculate the flow rate (F) through the roots meter as follows:

$$F = \frac{(V_F - V_I)}{t} \times \frac{(P - \Delta P)}{(T + 273)} \times \frac{298}{760}$$

12. Repeat Steps 5 through 11; and report F, V_F, V_I, t, P, ΔP, and T for each filter that is tested.

13. After every 10 filters, place the 7-hole resistance plate in the filter holder and measure and record the flow rate. If flow is outside 40 ± 1 cu ft/min (1.13 ± .028 M^3/min), adjust the variable voltage transformer until flow rate is between 39 and 41 cu ft/min (1.104 and 1.161 M^3/min), and repeat flow rate measurement for the previous 5 filters.

AREAL Visual Inspection Test for Quartz and Glass Fiber Filters

1. Applicability

All quartz and glass fiber filters selected for physical and chemical testing as part of AREAL filter acceptance testing shall be checked for visual defects using this test procedure prior to conducting any other physical or chemical acceptance tests on them.

2. Definitions

a) Reject Filter: A reject filter is considered one not useable for the SLAMS samplers.

b) Defective Filter: A defective filter is considered useable for the SLAMS samplers but contains one or more visual defects.

3. Visual Inspection Procedure:

The filters will be placed individually on a light box or equivalent device and examined for the following imperfections:

a) Imperfections That Will Cause a Filter to be Classified as Rejected:

1. PINHOLE - A small hole that can be identified by examining both the front and the back of the filter.

2. TWO OR MORE DENSE SPOTS OR ONE DENSE SPOT LARGER THAN 0.25 INCHES IN DIAMETER - A dense spot is one which appears as a dark area without sharply defined edges when the filter is viewed from the back and an accumulation of filter fibers is seen when the filter is viewed from the front.

3. TWO OR MORE DARK SPOTS - A dark spot is a spot that resembles a fly speck in appearance.

4. NUMEROUS LOOSE FIBERS/LOOSE FIBERS THAT CANNOT BE BRUSHED OFF - These appear as if a rough object had been drawn across the back of the filter which loosened the filter base. The filters cannot be removed by gently brushing them with a camel hair brush.

5. INDIVIDUAL FIBER ON FILTER SURFACE - This will appear as either a pinhole or as a thin spot on the filter's surface. During sampling this fiber may separate from the filter mat causing a pinhole in the filter.

6. FILTER NOT NUMBERED - A filter that is not identified by a unique number or whose number cannot be read.